



# Creating The Right Atmosphere: An Autoregressive Method For Generating Realistic Atmospheres in Adaptive Optics Simulations

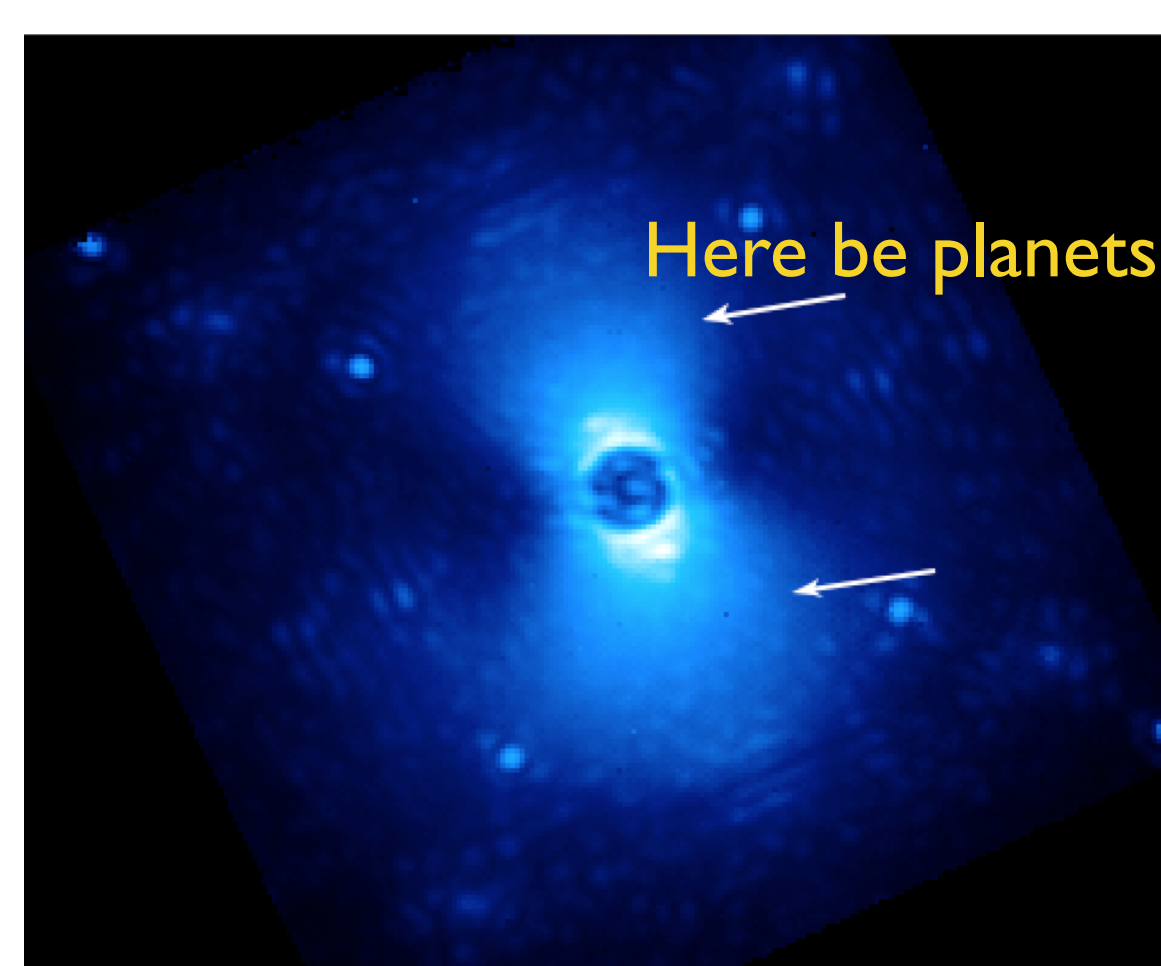
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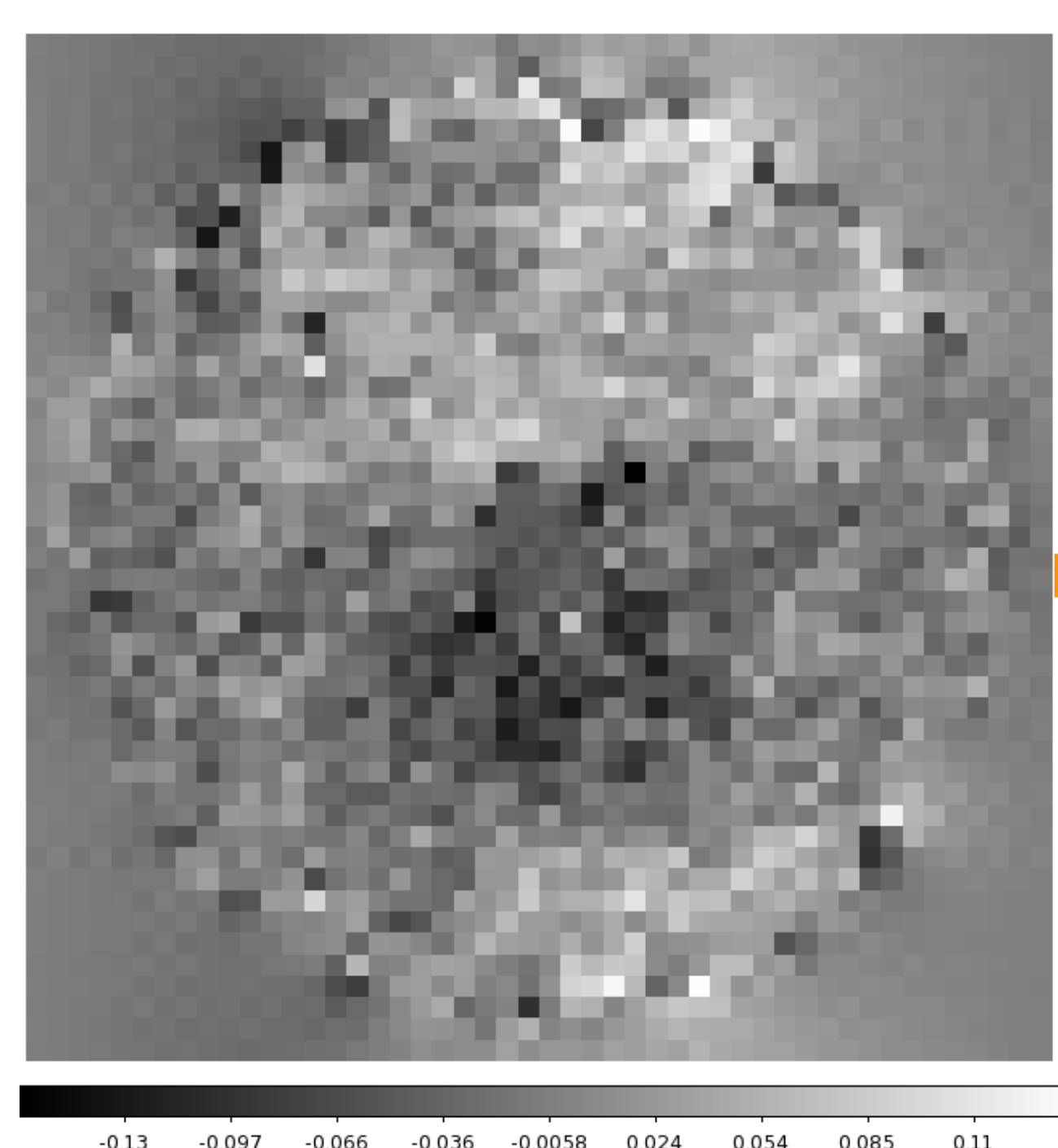


GPI Image



- “Wind butterfly” causes extra speckles, reduced contrast in “dark hole”
- Removal by post-processing results in information loss (e.g. debris disks)

Closed-loop residual phase - Telemetry



Error/Noise Transfer Functions

$$ETF = \left| \frac{1}{1+C(z)z^{-2}} \right|^2$$

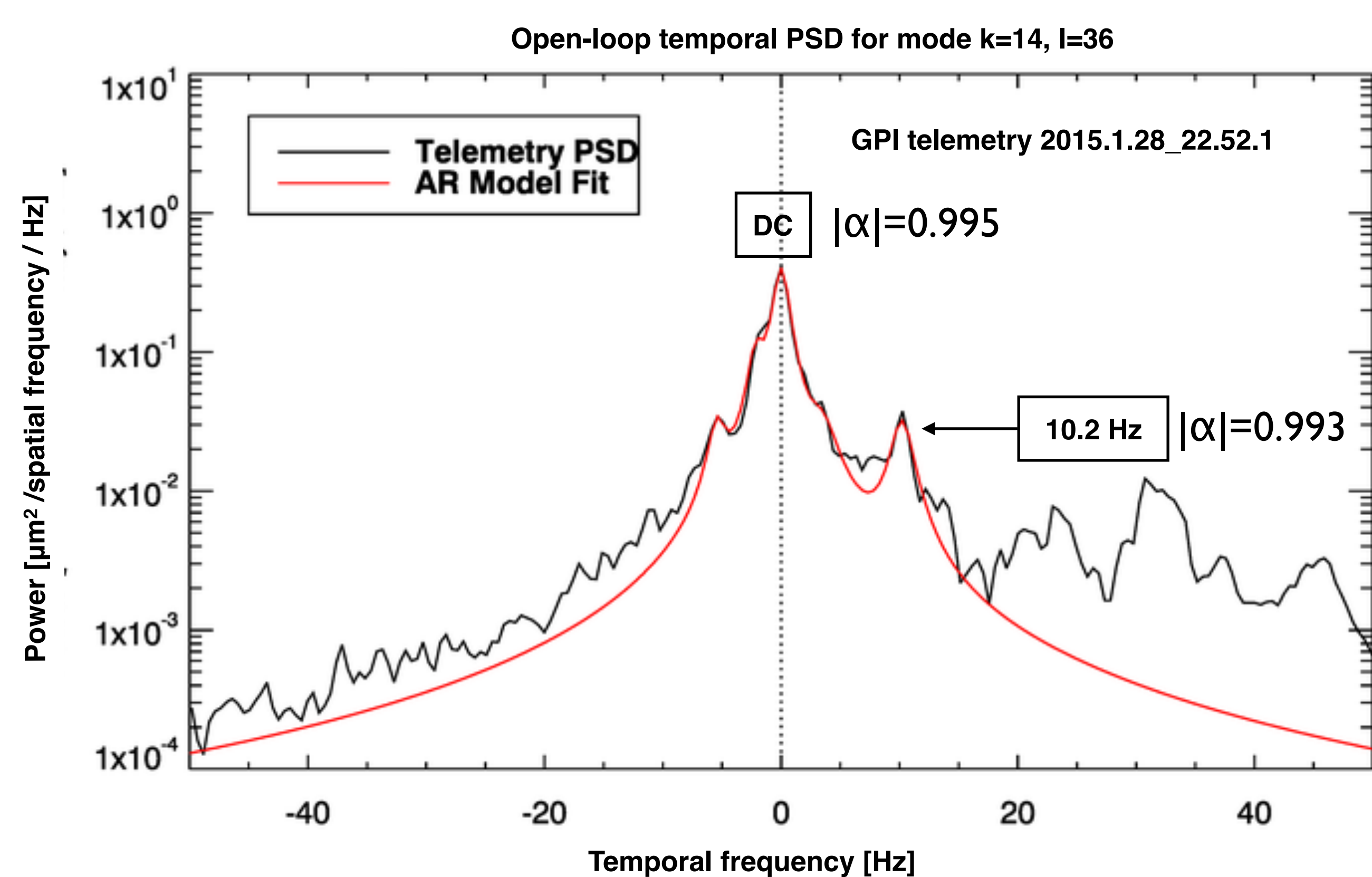
$$C(z) = \frac{g}{(1-cz^{-1})}$$

$$0 < g < 1, c \sim 1$$

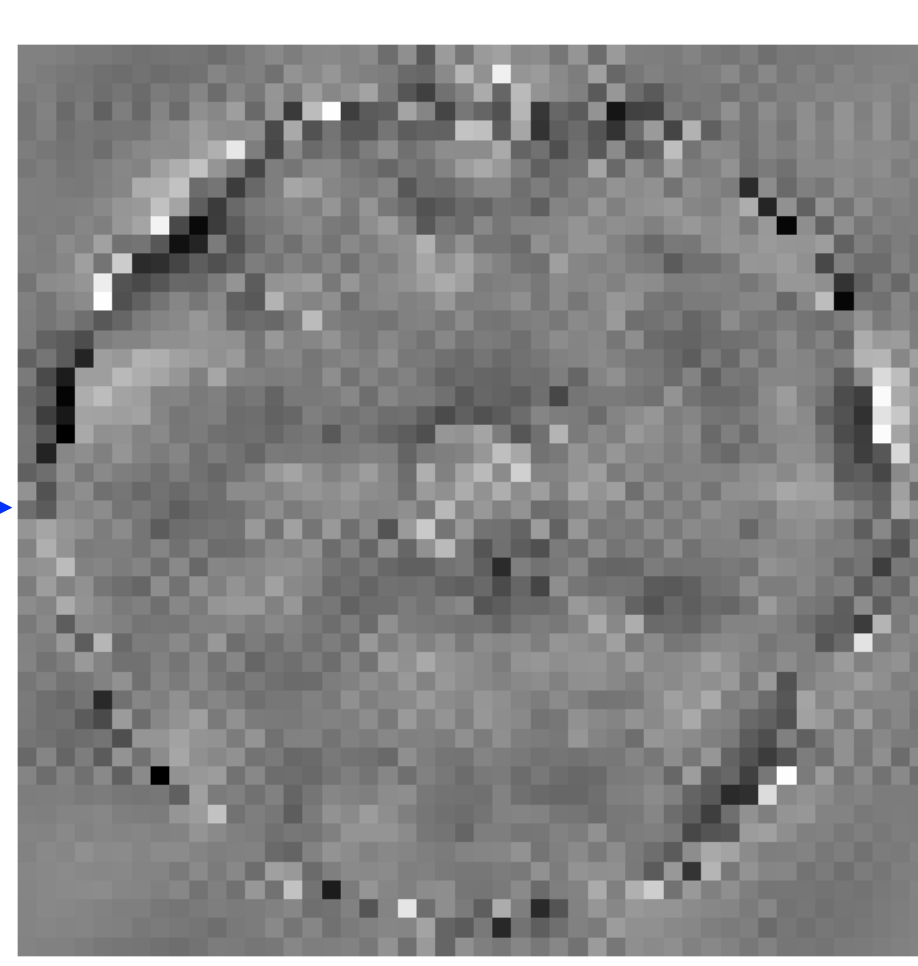
$$P_{CL} = ETF(P_{\phi} + P_N)$$

ETF = Error Transfer Function  
P<sub>CL</sub> = Est. closed-loop phase PSD  
P<sub>φ</sub> = Open-loop phase PSD  
P<sub>N</sub> = Closed-loop noise PSD  
g = gain  
c = integrator leak

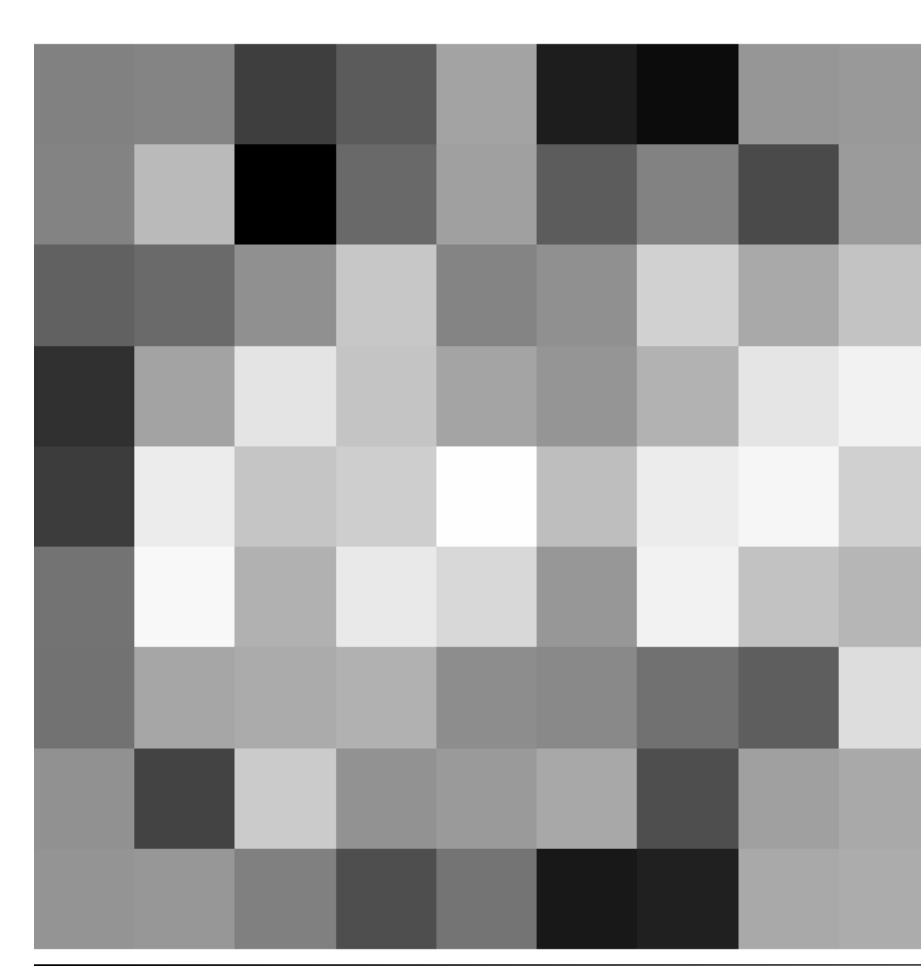
Open-loop phase Temporal PSD



DM commands - Telemetry

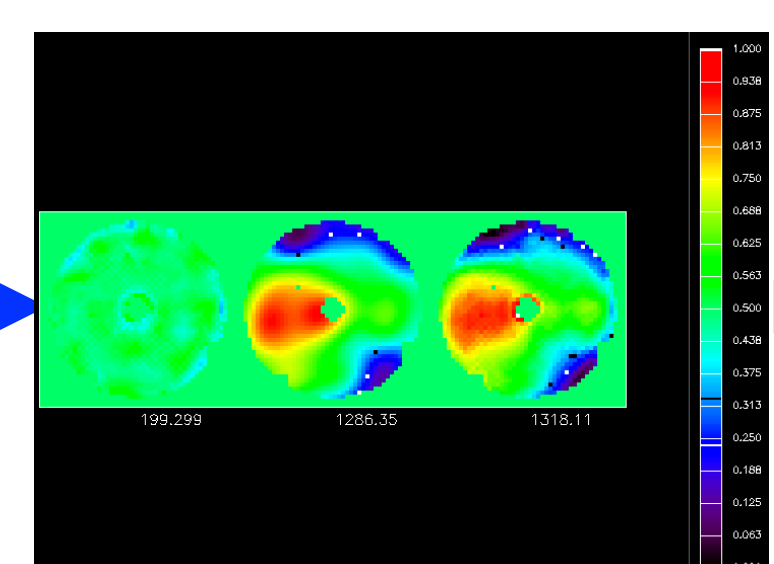


Tweeter commands

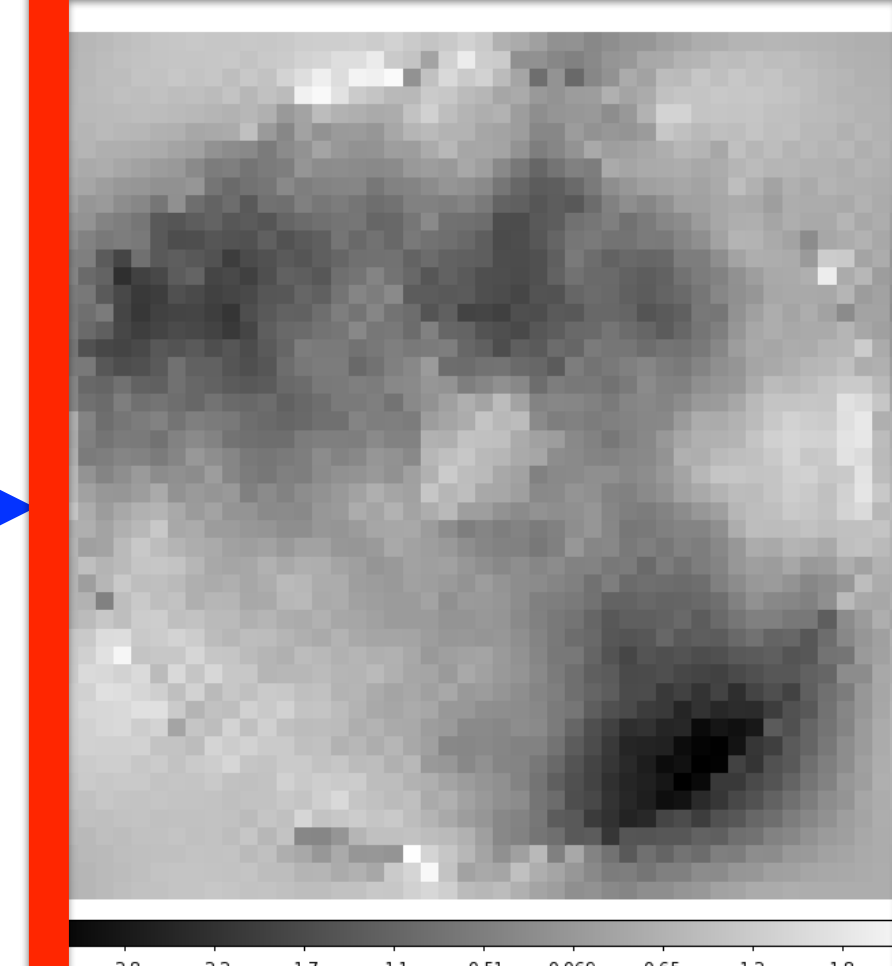


Woofer commands

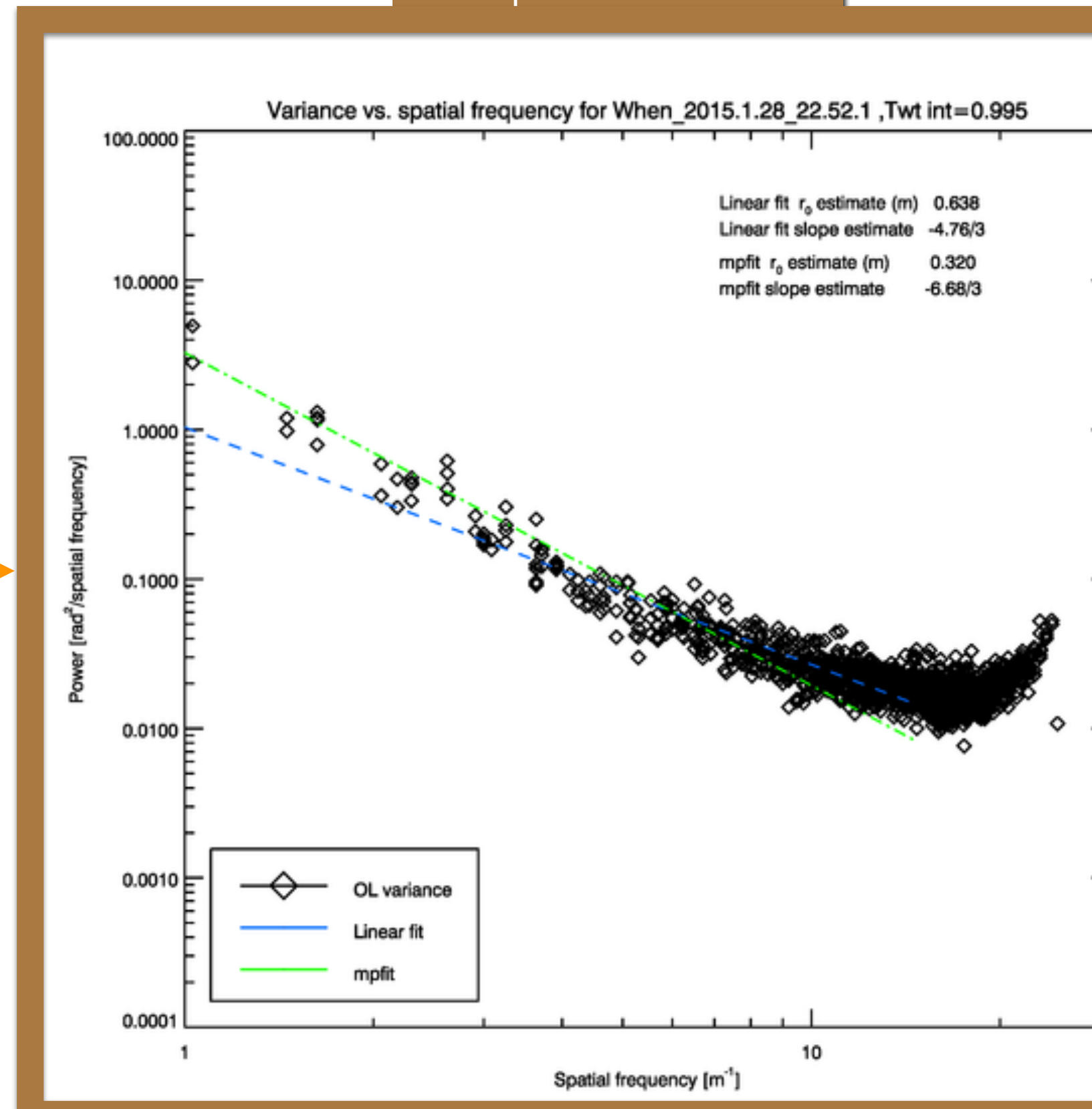
Telemetry Analyzer & DM reconstruction



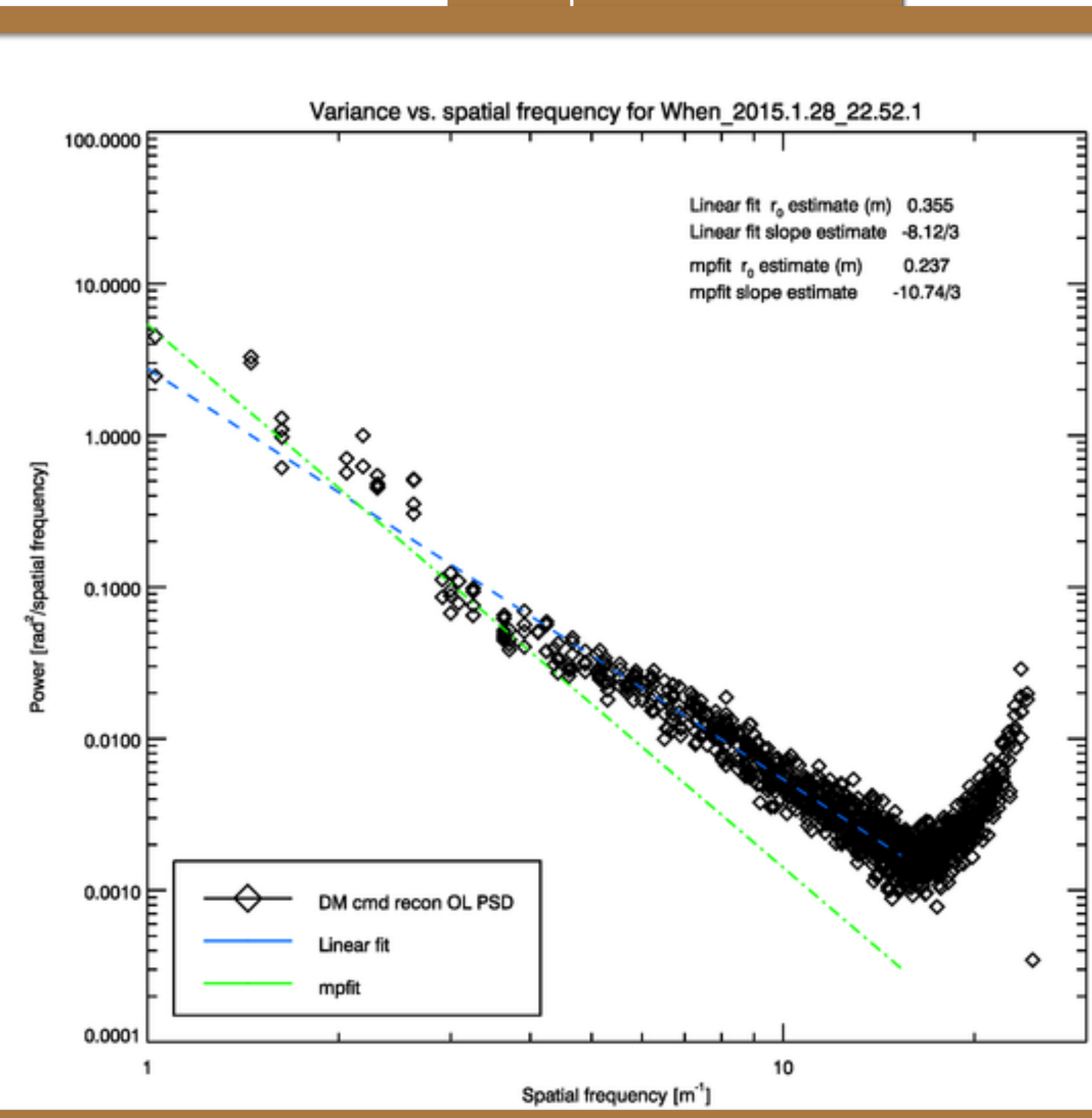
Open-loop phase from DM cmds



Open-loop phase Spatial PSD



Open-loop phase Spatial PSD



Fourier Wind Identification

|α|, v<sub>x</sub>, v<sub>y</sub>

r<sub>0</sub>

AR(1) atmosphere generator

$$P \propto \frac{2\pi}{D} N r_0^{-5/6} (f_x^2 + f_y^2)^{-11/12}$$

$$\tilde{\phi}_t = \alpha \tilde{\phi}_{t-1} + \sqrt{1 - |\alpha|^2} P \tilde{\omega}_t$$

$$\theta = -2\pi T (f_x v_x + f_y v_y)$$

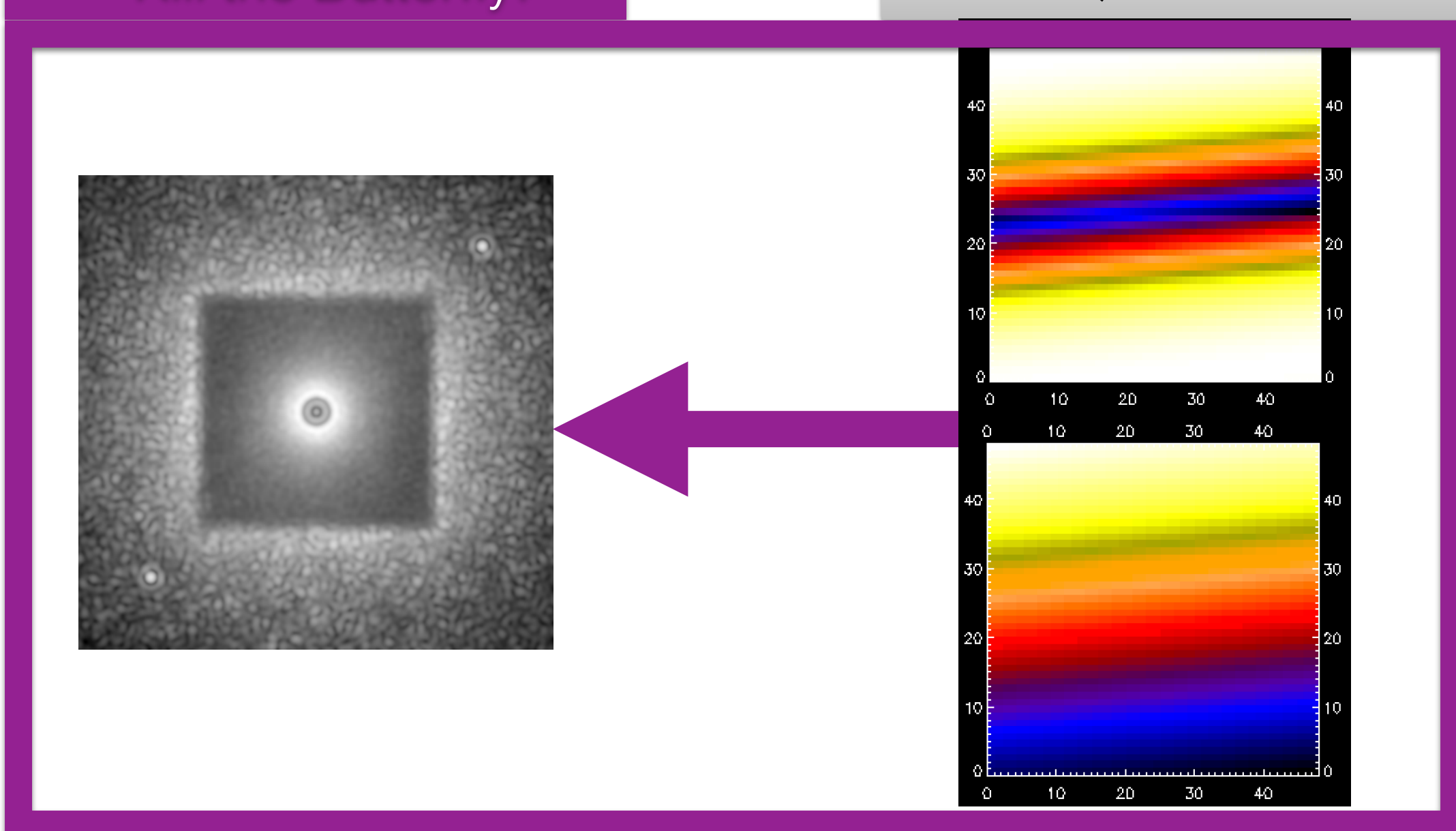
where:

$$FT(\phi_t) = \tilde{\phi}_t \quad \alpha = |\alpha| e^{-i\theta}$$

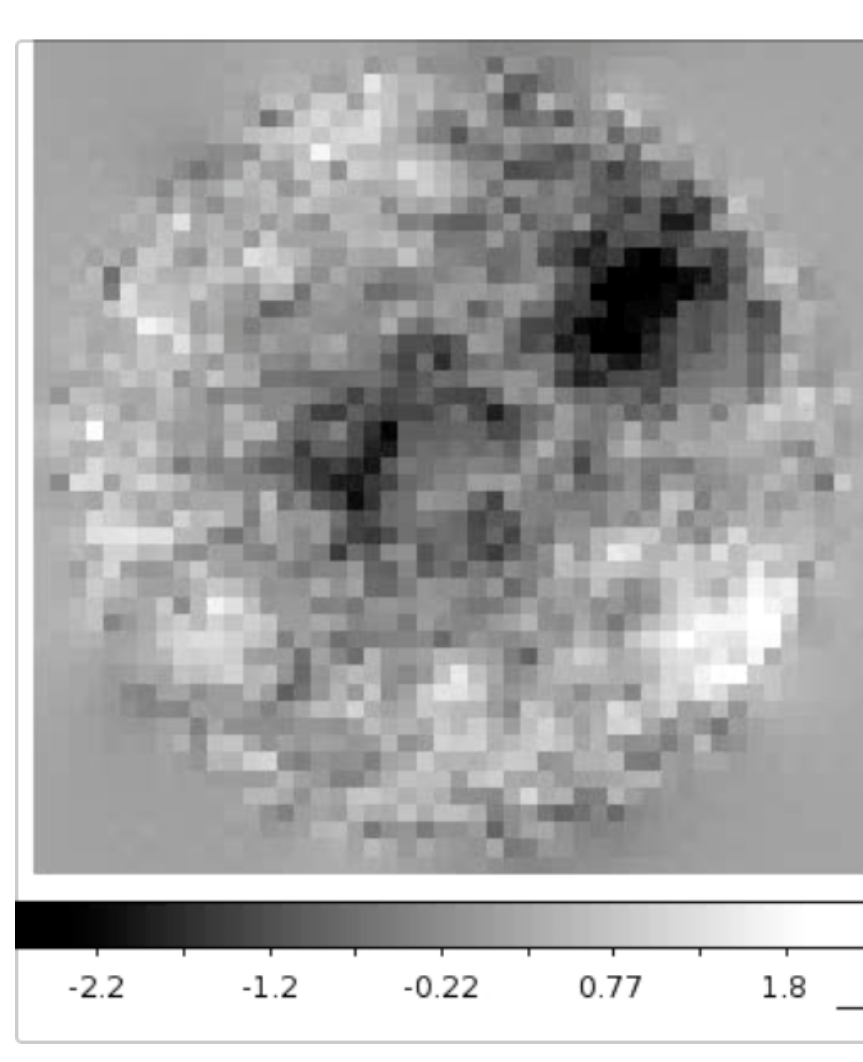
- D = screen diameter in meters
- N = number of pixels across screen
- ω = spatially white noise σ<sub>ω</sub><sup>2</sup> = 1
- T = sampling interval (in seconds)

AO with Wind Prediction - Kill the Butterfly!

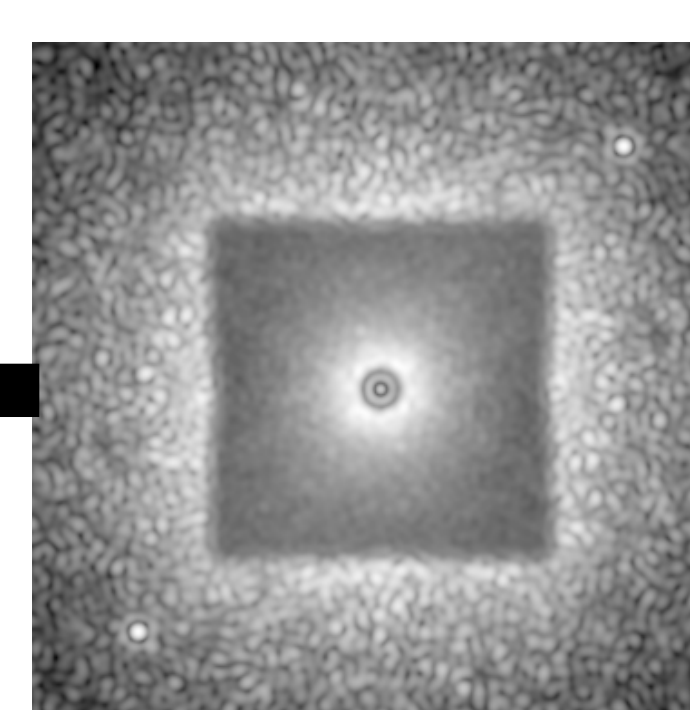
Kalman filter generator for LQG controller



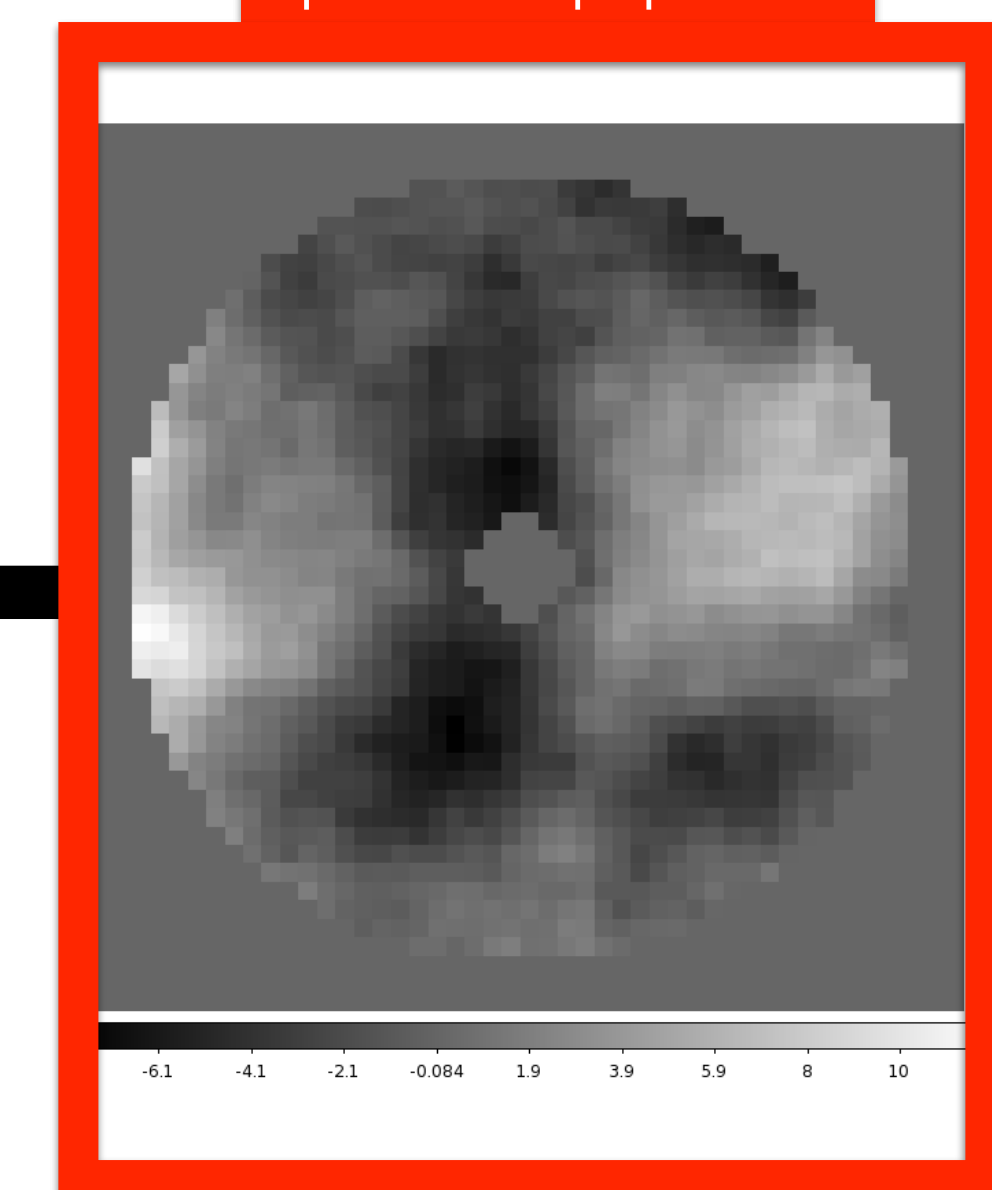
Closed-loop residual phase - sim output



GPI AO Simulator



Autoregression open-loop phase



## Motivation and Future Work

- Wind prediction will minimize temporal errors, remove the “wind butterfly” and improve contrast in the “dark hole”.
- AR(1) atmospheres reflect measured real-world conditions, do not exhibit periodicity, can have custom spatial power spectra, are memory efficient and allow for long-exposure simulations (tens of seconds).
- Extracting meaningful parameters (like r<sub>0</sub>) from closed-loop residual phase or reconstructed pseudo-open loop phase (from DM commands or via the system transfer function) is non-trivial and ongoing. Please talk to me if you have ideas!

## References

1. Srinath et al, OpEx, 2015 (submitted)
2. Poyneer et al, JOSAA Vol. 24 #9, 2007
3. Poyneer et al, JOSAA Vol. 26 #4, 2009
4. Johansson et al, SPIE 2200, 1994
5. Rudy et al, OpEx, 2015 (submitted)